Trans-Lake Washington Project

Noise Mitigation and Design Options

Methods of Analysis and Mitigation for
Traffic and Transit Projects

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ACRONYMS

dB	decibel
dBA	A-weighted decibel
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
HT	heavy trucks
HUD	Housing and Urban Development
HVAC	heating, ventilation and air conditioning
LRT	light rail transit
MT	medium trucks
PVC	polyvinyl chloride
RSIP	Residential Sound Insulation Program
TNM	traffic noise model
WAC	Washington Administrative Code
WSDOT	Washington State Department of Transportation

1. INTRODUCTION

The purpose of this technical report is to provide the Trans-Lake Washington Project design team with general information on noise, available noise mitigation measures, and alignment design methods that would assist in reducing project-related noise impacts. The report contains several sections, including information on agency coordination, an introduction to noise, methods of traffic-noise analysis, and a detailed section on noise mitigation and noise-reducing design methods. Several figures and tables are also included to assist in understanding propagation of traffic noise and mitigation methods.

2. AGENCY COORDINATION AND COOPERATION

Agency involvement is currently under way and is expected to continue throughout the project. Federal agencies with project involvement include the Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA). In addition, coordination with the Washington State Department of Transportation (WSDOT), Sound Transit King County, and the cities of Seattle, Bellevue, Kirkland and Redmond will occur as the project progresses.

3. INTRODUCTION TO NOISE

Sound is defined as any pressure variation that the human ear can detect, from barely perceptible sounds to sound levels that can cause hearing damage. The magnitude of air pressure variation from normal (or static) air pressure is a measure of the sound level. The number of cyclic pressure variations per second is the frequency of sound. When sounds are unpleasant, unwanted, or disturbingly loud, they tend to be classified as noise.

Compared with normal air pressure, audible sound pressure varies from the threshold of hearing (a very small 20 µPa [20 x 10^{-6} pascals]) to 100 pascals (a level so loud it is referred to as the threshold of pain). Using pascals to describe sound levels can be awkward because the ratio between these numbers is more than a million to one. A more convenient unit to measure sound levels is the decibel (dB), which is a logarithmic conversion of air pressure level variations from pascals. This conversion not only allows for a more convenient scale, but also is a more accurate representation of how the human ear reacts to variations in air pressure.

The smallest noise-level change that can be detected by the human ear is approximately 3 dB. A 5-dB change in noise levels is clearly noticeable, and an increase of 10 dB is roughly equivalent to a doubling in the perceived sound level. Under free-field conditions, where there are no reflections or additional attenuation, a point sound is known to decrease at a rate of 6 dB each time the distance from the source is doubled. This is commonly known as the inverse square law. For example, a sound level of 70 dB at a distance of 100 feet would decrease to 64 dB at 200 feet, or 58 dB at 400 feet. For a line source, such as a roadway, the contribution of each source on the roadway must be considered, which results in an ideal reduction of approximately 3 dB for each doubling of distance.

In acoustic measurements, where the primary concern is the effect on humans, an A-weighted filter is normally used to compensate for the sound level readings. The A-weighted filter accounts for the limited hearing response of the human ear in the upper and lower frequency bands. Sound pressure level measurements made using the A-weighted filter are denoted dBA. Most ordinances and standards use the A-scale, including the standards applicable to this project.

Two noise metrics are commonly used for the analysis of highway and high capacity transit projects. The first is the equivalent sound pressure level, L_{eq}. The L_{eq} is defined as the average noise level, on an energy basis, for a stated time period (for example, hourly). The second commonly used noise-level metric is the daily descriptor, L_{dn}. The L_{dn} is a 24-hour equivalent continuous level in dBA where 10 dB is added to nighttime noise levels between the hours of 10:00 p.m. to 7:00 a.m. The 10 dBA weighting factor helps to account for nighttime-sensitivity to noise in residential areas. Other commonly used noise descriptors include the L_{max}, L_{min}, and the statistical noise descriptor, L_x. Definitions and symbols for each descriptor are given in Table 1 and detailed information on acoustical formulas, other project-related noise-level descriptors, and graphics of typical noise levels are given in Appendix A.

Table 1. Noise Descriptors

Symbol	Description
L_{eq}	The average noise level (energy basis)
L_{dn}	The 24-hour average noise level with a 10-dBA penalty added to nighttime (10 p.m. to 7 a.m.) levels
L_{max}	The maximum noise level
L_{min}	The minimum noise level
L_x	The noise level that is equaled or exceeded for "x" percent of the time (for example, during a 1-hour measurement, an L_{50} of 67 dBA means the sound level was at or above 67 dBA for 30 minutes during that hour)

Several factors determine how sound levels diminish over distance. Under ideal conditions, a point noise source in free space will attenuate at a rate of 6 dB each time the distance from the source doubles (using the inverse square law). An ideal line source (such as constant flowing traffic on a busy highway) reduces at a rate of approximately 3 dB each time the distance doubles. Under real-life conditions, however, interactions of the sound waves with the ground often result in attenuation that is slightly higher than the *ideal* reduction factors given above. Other factors that affect the attenuation of sound with distance include existing structures, topography, foliage, ground cover, and atmospheric conditions such as wind, temperature, and relative humidity. The following list provides some general information on how these factors may potentially affect sound propagation.

- **Existing Structures.** Existing structures can have a substantial effect on noise levels in any given area. Structures can reduce noise by physically blocking sound transmission and, under special circumstances, may cause an increase in noise levels if sound is reflected off the structure and transmitted to a nearby receiver location. Measurements have shown that a single-story house has the potential, through shielding, to reduce noise levels by as much as 10 dB or greater. The actual noise reduction will depend greatly on the geometry of the noise source, receiver, and location of the structure. Increases in noise caused by reflection are normally 3 dB or less, which is the minimum change in noise levels that can be noticed by the human ear.

- **Topography**. Topography includes existing hills, berms, and other surface features between the noise source and receiver location. As with structures, topography has the potential to reduce or increase sound depending on the geometry of the area. Hills and berms, when placed between the noise source and receiver, can have a significant effect on noise levels. In many situations, berms mitigate noise by physically blocking the noise source from the receiver location. In some locations, however, the topography can result in an overall increase in sound levels by either reflecting or channeling the noise towards a sensitive receiver location.

- **Foliage.** Foliage, if dense, can slightly reduce noise levels. FHWA provides for up to a 5 dBA reduction in traffic noise for locations with at least 30 feet of dense evergreen foliage. Because foliage varies in the project area, no reduction for foliage will be used in the analysis.

- **Ground Cover.** The ground cover between the receiver and the noise source can have a significant effect on noise transmission. For example, sound will travel very well across reflective surfaces such as water or pavement, but can be attenuated when the ground cover is field grass, lawns, or even loose soil. During the environmental impact statement phase of the project, detailed information related to sound transmission in the project area will be compiled through a combination of onsite monitoring, noise modeling, and published information. This information will be used during the final noise modeling to account for the varying ground conditions in the project area.

- **Atmospheric Conditions**. Atmospheric conditions that can affect noise transmission include wind, temperature, humidity, and precipitation. Wind can increase sound levels if it is blowing from the noise source to the receiver; conversely, it can reduce noise levels if blowing in the opposite direction. Noise propagation can also be significantly affected when the temperature gradient is such that an inversion is formed. Other atmospheric conditions such as humidity and precipitation are rarely severe enough to result in significant changes in noise level propagation.

4. LAND USE CONSIDERATIONS

The existing land use, not the land use zone, determines the noise impact criteria level for highway and high capacity transit projects. Therefore, if a parcel of land is zoned commercial, but is still occupied by a residence, the residential impact criteria apply. Under special circumstances, if land use in a specific area is changing, or if changes are planned as part of the project, the new land use can be used to determine impacts. For example, if a residential area is to be replaced with commercial use prior to final construction of a project, the new land use could be used to determine the level of noise impact.

The FHWA and the FTA each have a method to categorize land use in a corridor. Lands use types established by the FHWA for traffic-noise analysis include five categories shown in Table 2.

Table 2. FHWA Land Use Categories

Type	Land Use Description
A	Lands on which serenity and quiet are of extraordinary significance and serve an important public need, and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose
B	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, (exterior) motels, hotels, schools, churches, libraries, and hospitals
C	Developed lands, properties, or activities not included in the above categories
D	Undeveloped land
E	Interiors of residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums

The FHWA uses outdoor locations to determine noise impacts, except in special circumstances. Noise measurements for land use categories Type A through Type D are all taken 1.5 meters off the ground at a distance at least 5 meters from the nearest structure on the property. Land use category Type E is used only for noise-sensitive land use where there is no outdoor use at the location or for those locations where the interior noise levels are the main concern, such as a library.

The FTA noise impact criteria groups noise-sensitive land uses into three categories. The land use categories are given in Table 3.

Under the FTA criteria, there are no impact criteria for commercial and industrial land uses, unless the site is noted as sensitive to noise. Examples of noise-sensitive uses could include recording studios, concert halls, and other similar land uses. Depending on the circumstances and land use, the appropriate FTA category will be applied to noise-sensitive uses.

Table 3. FTA Land Use Categories

Category	Land Use Description
1	Buildings or parks where quiet is an essential element of their purpose
2	Residences and buildings where people normally sleep. This includes residences, hospitals, and hotels where nighttime sensitivity is assumed to be of utmost importance
3	Institutional land uses primarily with daytime and evening use. This category includes schools, libraries, churches, and office buildings

5. NOISE MODELING METHODOLOGIES

A general understanding of traffic and transit noise prediction modeling may be helpful when working on project design issues. The following sections contain some general information on the methods used for traffic and transit noise modeling.

5.1 TRAFFIC-NOISE MODELING METHODS

Traffic-noise levels are calculated using FHWA-approved noise models. Currently, there are two noise models approved for highway-related noise projects. The first is the *FHWA Highway Traffic Noise Prediction Model* (USDOT, 1978), as coded in the computer model described in the *Noise Barrier Cost Reduction Procedure, STAMINA 2.0, OPTIMA User's Manual* (USDOT, 1982), developed for FHWA. The second is the newer *FHWA Highway Traffic Noise Prediction Model* Version 1.1 (USDOT, 1998). Because the Record of Decision is expected after the traffic noise model (TNM) phase-in cut-off date of December 2002, TNM is recommended for the detailed analysis of the Trans-Lake Washington Project.

Input to both models included traffic volume and speed data generated by project traffic engineers. Noise emission levels used in the models are nationwide averages for automobiles, medium trucks, and heavy trucks. In addition to the traffic information, noise-reducing effects of front-line[1] residences, roadway depressions, and topography are included in the calculations where appropriate. Using the above information, the models predict the hourly L_{eq} at selected receiver locations along the project corridor.

The results of the noise modeling are compared to the FHWA/WSDOT traffic-noise criteria, and potential traffic-noise impacts are identified. Where impacts are identified, a mitigation analysis would be performed. During the mitigation analysis, noise barriers, berms, and other mitigation measures can be added to the model input, and the noise reduction from the mitigation measure would be calculated.

5.2 TRANSIT NOISE MODELING METHODS

Noise modeling for high capacity transit projects is performed in a similar manner to the traffic-noise modeling. A noise prediction model, developed by the FTA, is based on noise levels that would be generated by the type of transit proposed, such as for light rail or commuter rail transit projects. The model equations are provided in the FTA *Transit Noise and Vibration Impact Assessment Manual* (USDOT, April 1995). Reference noise levels for the projections would be based on noise levels generated by similar vehicle types.

As with the traffic-noise analysis, noise-reducing effects of front-line residences, alignment depressions, and topography are included in the calculations where appropriate. Using the information given above, along with transit schedules, either an hourly L_{eq} or a 24-hourly L_{dn} would be projected and compared to the FTA noise impact criteria, and transit impacts would be identified. Where impacts are identified, a

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[1] For the purpose of this report, "front-line" refers to noise-sensitive receivers located directly adjacent to the project roadway.

mitigation analysis would be performed. During the mitigation analysis, noise barriers, berms, and other mitigation measures could be added to the model input, and the noise reduction from the mitigation measure would be calculated.

5.3 NOISE IMPACT CRITERIA

The primary impact criteria for traffic noise are taken from the FHWA. For fixed guideway high capacity transit, the noise criteria are taken from the FTA. These criteria will be used to determine impacts for the Trans-Lake Washington Project. Other noise regulations, such as those for Washington State, that may be applicable to construction and ancillary facilities, would also be provided. The noise impact criteria and their applicability to the project are discussed in the following sections.

5.3.1 Federal Highway Administration

Title 23 of the Code of Federal Regulations Part 772, *Procedures for Abatement of Highway Traffic Noise and Construction Noise*, provides the traffic-noise impact criteria against which the project traffic-noise levels would be evaluated. The criteria applicable for residences, churches, schools, recreational uses, and similar areas is an exterior hourly equivalent sound level (L_{eq}) that approaches or exceeds 67 dBA. The criteria applicable for other developed lands, such as commercial and industrial uses, is an exterior L_{eq} that approaches or exceeds 72 dBA. The FHWA also considers a traffic-noise impact to occur if future noise levels are projected to result in a "substantial increase" over existing noise levels. Finally, for locations where the noise levels are projected to exceed the criteria by 5 dBA or more, or to increase by 15 dBA or more, a review for consideration of significant impacts may be performed in consultation with WSDOT and FHWA. There are no criteria for underdeveloped lands or construction noise. A summary of the FHWA noise regulations by land use is contained in Table 4.

Table 4. FHWA Roadway Noise Abatement Criteria

Type	Land Use Description	Hourly L_{eq} (dBA)
A	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose	57 (exterior)
B	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, (exterior) motels, hotels, schools, churches, libraries and hospitals	67 (exterior)
C	Developed lands, properties, or activities not included in the above categories	72 (exterior)
D	Undeveloped land	--
E	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums	52 (interior)

5.3.2 WSDOT Noise Regulations

Traffic-noise analysis for the Trans-Lake Washington Project will be performed to meet the requirements given by the WSDOT *Traffic Noise Analysis and Abatement Policy and Procedures Manual* (1997). WSDOT considers a traffic-noise impact to occur when predicted project-related noise levels approach the criteria level within 1 dBA, or when project-related noise levels substantially exceed existing levels. Therefore, residential impacts occur at 66 dBA and commercial impacts at 71 dBA. WSDOT also considers a 10 dBA increase substantial if the resulting noise level is greater than 50 dBA.

5.3.3 Federal Transit Administration

The analysis of high capacity transit noise sources will be performed using the FTA impact criteria. The FTA uses a sliding-scale noise impact criterion that has two levels of impact—severe and moderate. The two distinct levels for noise impact under FTA Category 2 for transit operations are defined below and shown in Figure 1.

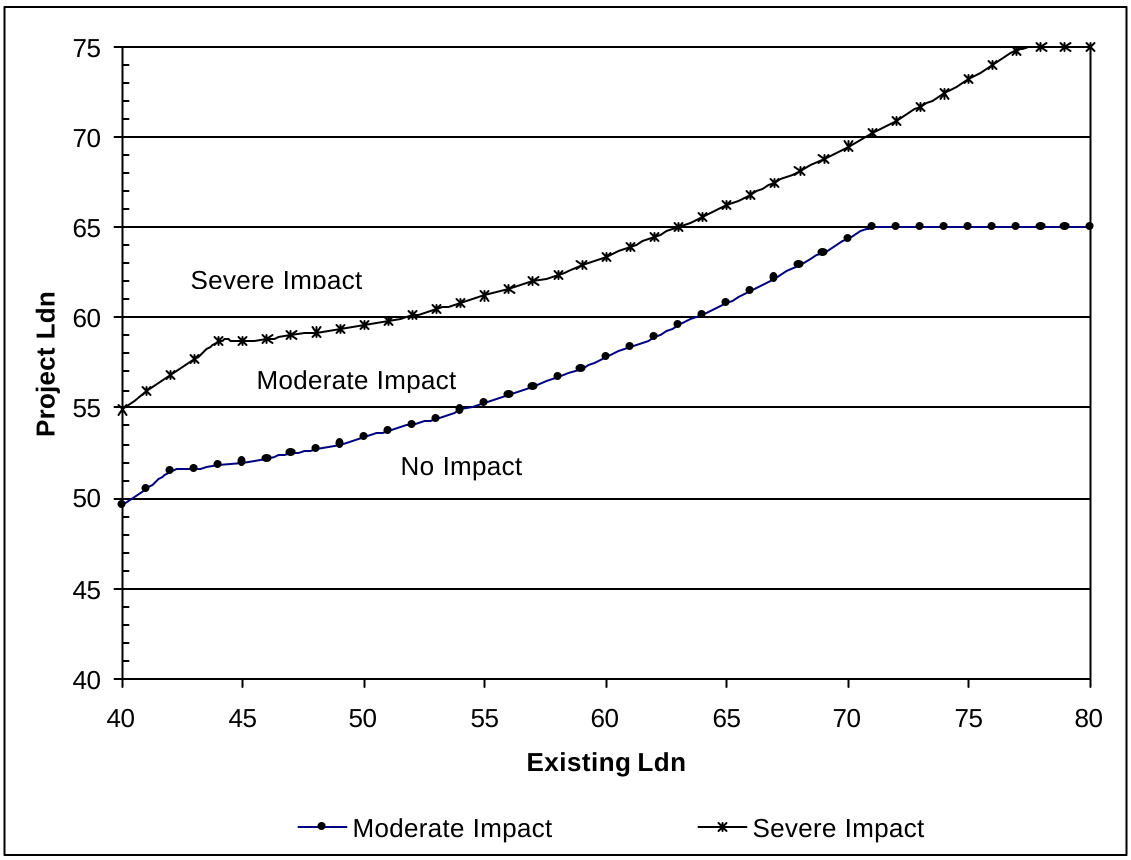

Figure 1. FTA Noise Impact Criteria

- **Severe Impact.** Severe noise impacts are considered "significant" as used in the National Environmental Policy Act and implementing regulations. Noise mitigation normally will be specified for severe impact areas, unless there is no practical method for mitigating the noise.

- **Moderate Impact.** For this level, other project-specific factors must be considered to determine the magnitude of the impact and the need for mitigation. These project-specific factors can include the predicted increase over existing noise levels, the types and number of noise-sensitive land uses affected, existing outdoor-indoor sound insulation, and the cost effectiveness of mitigating noise to more acceptable levels.

Future noise exposure would be the combination of the existing noise exposure and the additional noise exposure caused by the Trans-Lake Washington Project. As the existing noise exposure increases, the amount of the allowable increase in the overall noise exposure caused by the project would decrease. For example, if the existing noise level is 65 dBA for Category 1 or 2 land use, an impact occurs if noise is projected to exceed 61 dBA (L_{eq} for Category 1, and L_{dn} for Category 2). The impact would be considered "severe" if the projected noise level were 66 dBA or higher.

5.3.4 State and Local Noise Regulations and Ordinances

There are several state, county, and local noise regulations and ordinances. Because many of the local regulations are based on the Washington Administration Code (WAC), only the WAC regulations are presented in this document. All other regulations and ordinances will be investigated to determine their applicability to the Trans-Lake Washington Project. Generally, state and local noise regulations only apply to project-related ancillary facilities, such as maintenance bases. Those that apply will be included during the noise impact analysis phase.

The WAC noise control ordinance defines three classes of property usage and the maximum noise levels allowable between them. For example, noise caused by a commercial property must be less than 57 dBA at the closest residential property line.

The WAC noise control ordinance applies to project-related construction activities and ancillary facilities, such as maintenance facilities and storage bases. Highway and high capacity transit noise on public roadways and rights-of-way are exempt from this ordinance. The WAC noise control ordinance is summarized in Table 5. Detailed information on construction noise regulations for Washington State are given in Appendix B.

Table 5. WAC Property Line Noise Control Ordinance[a]

Property Usage	Maximum Allowable Sound Level (dBA)		
	Residential	Commercial	Industrial
Residential	55	57	60
Commercial	57	60	65
Industrial	60	65	70

[a] The noise control ordinance is also used by several cities in the project area.

Between the hours of 10:00 p.m. and 7:00 a.m., the maximum allowable levels shown in Table 5 are reduced by 10 dBA for residential land uses. Besides the property line noise standards given in Table 5, there are exemptions for short-term noise exceedances based on the minutes per hour that the noise limit is exceeded. In addition, construction noise is exempt from the noise limits in Table 5 on weekdays and Saturdays, between the hours of 7:00 a.m. and 10:00 p.m. Nighttime construction activities would require a noise variance from the governing local agency. Table 6 summarizes the additional allowable noise level exceedances.

Table 6. Short-Term Noise Exceedance Exemptions

Maximum Minutes per Hour	Adjustment to Allowable Sound Level
15	+5 dBA
5	+10 dBA
1.5	+15 dBA

6. EXISTING ENVIRONMENT

Both FHWA/WSDOT and FTA noise regulations use existing noise levels to determine noise impacts. The existing noise environment is established through a combination of onsite noise monitoring, noise-level modeling, and data from other sources, such as the U.S. Environmental Protection Agency and other technical reports for the project corridor. Modeling for traffic noise is accomplished using existing traffic volumes, speed, and mix along the existing roadways, as described in Section 5. These methods will also be used for the Trans-Lake Washington Project.

There are several studies that have been performed in or near the Trans-Lake Washington Project corridor. This report cites two main studies, both performed by WSDOT, to provide a general understanding of the existing noise levels in the Trans-Lake Washington corridor.

The first study, *Olive to SR 520 Northbound HOV/SR 520 Reversible Roadway Connection Traffic Noise Analysis* (WSDOT, May 1988), provides noise levels in the project vicinity along the I-5 and SR 520 connection ramps. The second study, *SR 520 Arboretum Vicinity Traffic Noise Investigation* (WSDOT, June 1982) provides noise levels and mitigation options in four areas—Marshal Trail, Arboretum Lagoon Area, Foster Island, and Madison Park.

Based on these WSDOT studies, existing noise levels throughout the Trans-Lake corridor are projected at 69 to 75 dBA for close proximity (<100 feet) front-line receivers. Front-line receivers at greater distances, or with some shielding between the roadway and the receiver, are projected at 65 to 71 dBA. Second- and third-line receivers with some shielding are projected at 63 to 67 dBA. These estimates, which will vary depending on the distance and topography between the roadway and the receiver location, are provided for information purposes only.

During the formal environmental analysis phase of the project, detailed noise measurements would be performed and used, in conjunction with modeled noise levels, to describe the existing conditions. In addition, detailed descriptions of the study area, including existing noise sources, topography, and traffic characteristics would also be included. The information will be presented in text, informative tables, and on area figures and plan drawings.

7. TRANSPORTATION NOISE SOURCES

Noise sources associated with transportation projects can include passenger vehicles, medium trucks, heavy trucks and buses, and where proposed, light rail and/or other fixed guideway transit modes. Each of these vehicles produces noise; however, the source and magnitude of the noise can vary greatly depending on the vehicle type. For example, while noise from passenger vehicles occurs mainly from the tire-roadway interface, which is located at ground level, noise from heavy trucks is produced by a combination of noise from tires, engines, and exhaust, resulting in a nominal noise source that is approximately 8 feet above the ground. Having an understanding of these transportation-related noise sources, and where the noise is emitted from, can be beneficial during project design. The following list provides information on the types of transportation noise sources that could be part of the project, and describes the type of noise each produces.

- **Passenger Vehicles (cars)—Noise emitted from 0 to 2 feet above the roadway, primarily from tire-roadway interface**. This category includes normal passenger vehicles, small and regular pickup trucks, small to mid-size sport utility vehicles, and mini- and full-size passenger vans. Typical noise levels for passenger vehicles are 72 to 74 dBA at 55 mph at a distance of 50 feet.[2]

- **Medium Trucks (MT)—Noise emitted from 2 to 5 feet above the roadway, combined noise sources from tire-roadway interface and engine exhaust noise**. This category includes delivery vans such as UPS and Federal Express trucks, large sport utility vehicles with knobby tires, large diesel engine trucks, some towtrucks, city transit and school buses with under-vehicle exhaust, moving vans (U-haul-type trucks), small to medium recreational motor homes, and other larger trucks with the exhaust located under the vehicle. Typical noise levels for medium trucks are 80 to 82 dBA at 55 mph at 50 feet.[2]

- **Heavy Trucks (HT)—Noise emitted from 6 to 8 feet above the roadway surface; combined noise sources include tire-roadway interface, engine noise, and exhaust stack noise**. This category includes all log-haul tractor-trailers (semi-trucks), large towtrucks, dump trucks, cement mixers, large transit buses, motor homes with the exhaust located at the top of the vehicle, and other vehicles with the exhaust located above the vehicle (typical exhaust height of 12 to 15 feet). Typical noise levels for heavy trucks are 84 to 86 dBA at 55 mph at 50 feet.[2]

- **Light Rail Transit Vehicles (LRT)—Noise emitted from 0 to 2 feet above the rails, primarily from the steel wheel to rail interface.** LRTs are electric vehicles with the primary noise source at the wheel-rail interface. Other sources of noise from LRTs include electric motors to run onboard ancillary equipment, such as air conditioning, heating, and door operations. Motors used for normal operations also generate some noise. However, these sources are normally noticeable only at slow

[2] Source: *Development of National Reference Energy Mean Emission Levels for the FHWA Traffic Noise Model* (FHWA TNM), Version 1.0 (USDOT, November 1995).

speeds or when stopped at a station. Noise levels from LRTs range from 75 to 78 dBA at 40 mph at 50 feet.[3]

- **Commuter Rail Trains (Diesel Electric)—Noise source is usually 12 to 15 feet above the roadway**. No heavy rail is proposed for the Trans-Lake Washington Project.

- **Other High Capacity Transit Vehicles.** Several other vehicle types might be proposed as part of the project. If a vehicle type is proposed that is not currently in use in the Pacific Northwest, actual noise measurements from the FTA or the equipment manufacturer will be examined and used in the Trans-Lake analysis.

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[3] Source: *Central Link Light Rail Transit Project, Noise and Vibration Report* (Sound Transit, November 1999).

8. WHEN TO PROVIDE NOISE MITIGATION

Noise mitigation is considered for all new facilities and roadways, as well as the addition of capacity or alignment to existing facilities or roadways where noise impacts are identified. Noise mitigation can be performed at the source, along the path between the source and receiver, or at the receiver location. The primary forms of noise mitigation for transportation projects are noise walls and earth berms. Other forms of noise mitigation such as management measures, design measures, and sound insulation, which must also be considered, are described in Chapter 9.

The FHWA provides the states some leeway in determining when to provide noise mitigation. WSDOT makes consideration for traffic-noise abatement under two project types:

- **Type I**: A proposed project for the construction of a highway at a new location, or the physical alteration of an existing highway that significantly changes either the horizontal or vertical alignment or increases the number of traffic through-lanes.

- **Type II (Retrofit):** A proposed project for traffic-noise abatement on an existing highway. These are stand-alone projects and construction of these barriers is not necessarily associated with projects that provide capacity improvements. However, communities must meet the conditions of the WSDOT traffic noise impact criteria given in Section 5.4.1 and in Section 339(b)(2) of the National Highway System Designation Act of 1995.

The development and implementation of Type II projects are not mandatory; however, WSDOT maintains a retrofit list to improve noise abatement as funding allows. Retrofit projects are prioritized in an order reflecting traffic-noise levels, number of homes benefiting, cost, and achievable reductions. Barriers for Type II projects are normally constructed in their order of priority, but may be constructed as a Type I project or part of some other project. The Trans-Lake Washington Project is considered a Type I project, and mitigation will be considered for all identified project-related noise impacts.

The FTA requires that noise mitigation be investigated for all transit-related noise impacts. As with highway projects, the primary forms of mitigation are noise walls and earth berms. Other forms of mitigation that are also frequently used for high capacity transit projects include source mitigation, such as stringent vehicle and equipment noise specifications, operational restrictions, and, for fixed guideway transit projects, measures such as special track work. Receiver mitigation measures for FTA projects can also include sound insulation and property acquisition; however, these measures are not considered for WSDOT highway projects.

9. NOISE MITIGATION AND DESIGN OPTIONS

This section describes a wide range of mitigation and design options commonly used for major transportation projects. General information on the level of reduction from each mitigation measure is also provided. Several graphics showing detailed views of noise sources and mitigation provide useful information that can be used during the initial design phase of the project.

Whenever noise impacts are projected, several different noise abatement measures are evaluated. These include traffic management measures, highway design measures, and noise barriers such as earth berms. Other mitigation measures such as property acquisition and sound insulation are evaluated on a case-by-case basis, and are normally reserved for projects involving high capacity transit, or when the proposed project generates extremely high noise levels.

Any specific mitigation measures that are recommended as part of the project must be considered feasible and reasonable by WSDOT policies. Details on the feasibility and reasonableness of mitigation measures, along with design options and mitigation measures that may be applicable to the Trans-Lake Washington Project, are given in the following sections.

9.1 MANAGEMENT MEASURES

Management measures include modifying speed limits, restricting or prohibiting truck traffic, or closing roadways or access ramps during times when noise could have an adverse effect. The following sections describe how these methods may be used on the Trans-Lake Washington Project.

9.1.1 Speed Reduction

Speed reduction can reduce noise levels from vehicles. Reductions in noise levels of approximately 3 dBA for each 10 mph reduction in speed can be expected. However, this method is not seen as a potential mitigation or design option for the Trans-Lake Washington Project, as it would interfere with project objectives. Furthermore, the slight noise reduction that would be achieved would not significantly reduce noise levels or noise impacts.

9.1.2 Truck and Access Ramp Restrictions

Restricting truck use or closing access ramps on the project roadways would reduce noise levels at nearby receivers since trucks are louder than cars. However, this mitigation method could interfere with project objectives, and at this time is not considered a feasible form of mitigation for the Trans-Lake Washington Project. Restricting truck use or closing access ramps may be beneficial on some collector roadways that traverse neighborhoods and connect to the corridor. This mitigation design option method may be given further consideration during the environmental analysis phase.

9.2 DESIGN MEASURES

Highway design measures include altering the roadway alignment and depressing roadway cut sections. Alteration of roadway alignment could decrease noise levels by moving the noise source farther from the affected receivers. Because of the limited right-of-way in the project corridor, and the fact that noise impacts are expected to occur along both sides of the project roadway, this method is not seen as a feasible noise-reducing design option. In addition, realigning the Trans-Lake Washington Project would lower noise levels for residences on one side of the roadway, but would increase noise levels for residences on the other. Other design options that could be used to reduce noise levels, such as depressing the corridor or placing a lid over the roadway, are discussed in detail in the following sections.

9.2.1 Depressed Corridors

Depressed corridors are simply roadways placed below the grade of the noise-sensitive receiver locations. This method can be very effective in reducing noise levels at structures located within a few hundred feet of the project corridor. The depressed corridor is often bordered by a retaining wall or berm. Depending on the type of vehicle traffic and the level of corridor depression, a significant amount of noise can be blocked from reaching the noise-sensitive receiver locations.

Several different graphical representations are presented below that provide a general understanding of the overall effectiveness of depressed roadways. The graphics include three different receiver roadway geometries, including two retaining wall examples and one berm example, along with the potential noise reduction for each configuration. In addition, the graphics contain information on first-, second- and third-line receiver locations, and include typical receiver locations situated as much as 150 to 300 feet from the roadway alignment.

It should be noted that the noise-level reductions identified in this report are general in nature; actual noise reduction will depend on several variables. Major variables affecting noise reduction characteristics include traffic mix (cars, MT, and HT), distance from the receivers, shielding from other structures, and basic geometry between the receiver and roadway. Other less notable factors, such as ground cover and foliage, can also have a slight effect on noise-level reduction. Examples of depressed roadway cross sections are shown in Figure 2.

9.2.2 Depressed Corridors with Lids

Depressed corridors with lids are depressed roadways that are covered to provide community connection and for optimization of the project's vertical profile. The lids effectively prevent sound from reaching noise-sensitive receiver locations adjacent to the lidded area. For receivers located near the end points of the lidded roadway, additional noise mitigation such as noise walls may be necessary. The I-90 corridor across Mercer Island is a prime example of a lidded freeway.

One primary concern with lidded corridors is proper ventilation of vehicle exhaust. Lidded project corridors are essentially tunnels. Ventilation of the exhaust fumes is an important part of the design. Ventilation can be performed by leaving gaps or openings in the corridor lids to allow exhaust fumes to escape. If openings in the lids are used to ventilate the corridor, it should be noted that noise can also escape from these openings. Therefore, placing openings in locations as far as possible from noise-sensitive receivers can help to prevent additional noise impacts. For example, placing the opening near major arterial roads with access to the corridor is preferred because noise levels in this area are already elevated due to the traffic on the arterial road.

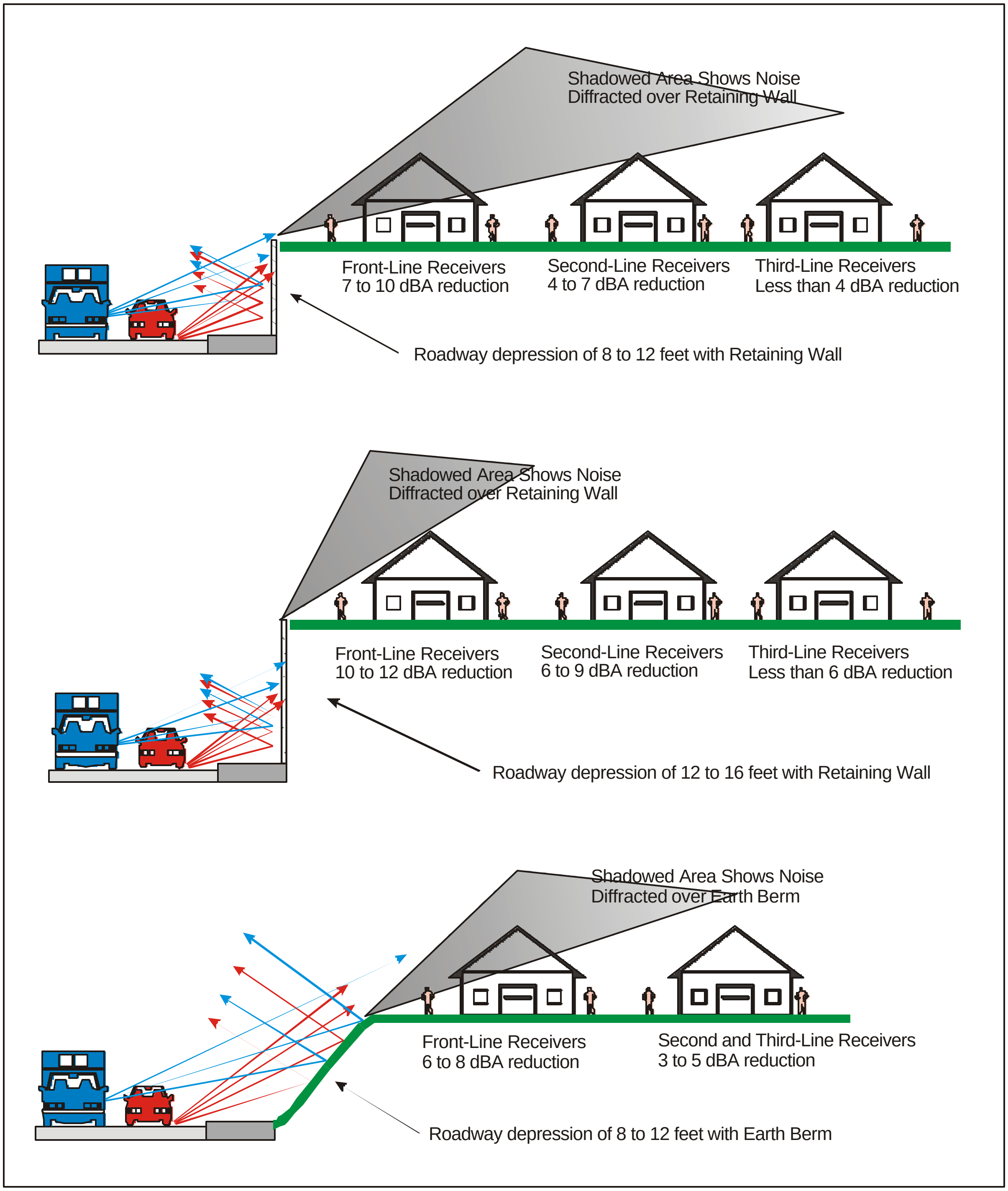


Figure 2. Examples of Depressed Roadways and Typical Noise Reduction Characteristics

Ventilation fans can also be used to evacuate vehicle exhaust. It should be noted that the fans themselves make noise, and incorrect placement of the fans could result in noise impacts. Also, because fans would have to run 24 hours a day, they should not be located near areas with nighttime sensitivity, such as residential areas. If no other location is available, it is possible to mitigate fan noise with noise-reducing louvers and silencers.

Furthermore, major arterial roads often have commercial and industrial land uses, and are therefore less noise-sensitive. Figure 3 provides an example of a depressed roadway with a lid and shows how the noise from vehicle traffic is contained.

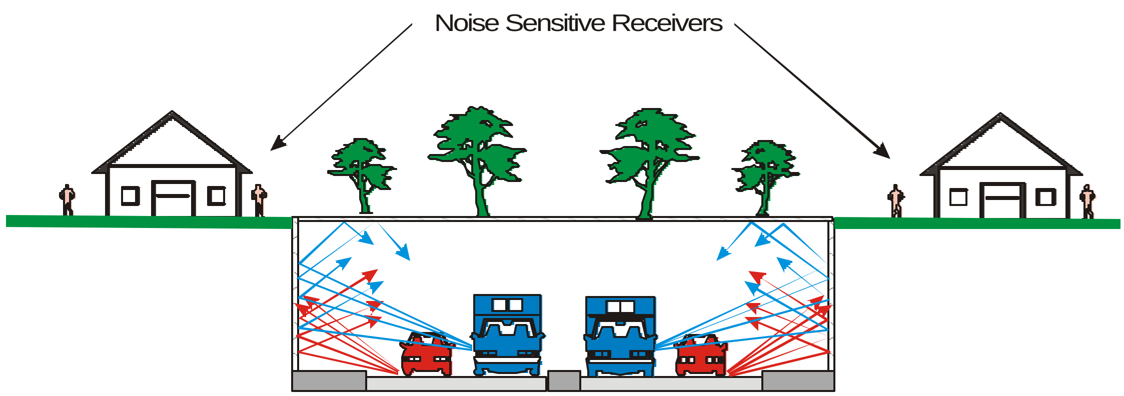


Figure 3. Typical Depressed Roadway with Lid

9.3 NOISE BARRIERS

For locations where noise-reducing design options are not feasible, other forms of noise mitigation may be reviewed and recommended for construction. The primary forms of noise mitigation for transportation projects are noise barriers. Construction of noise barriers between roadways and affected receivers reduce noise levels by physically blocking the transmission of traffic-generated noise. Barriers can be constructed as walls or earth berms. Earth berms require more right-of-way than walls and are usually constructed with a 3-to-1 slope. In many locations within the Trans-Lake Washington Project, berms may not be feasible because of the right-of-way requirement.

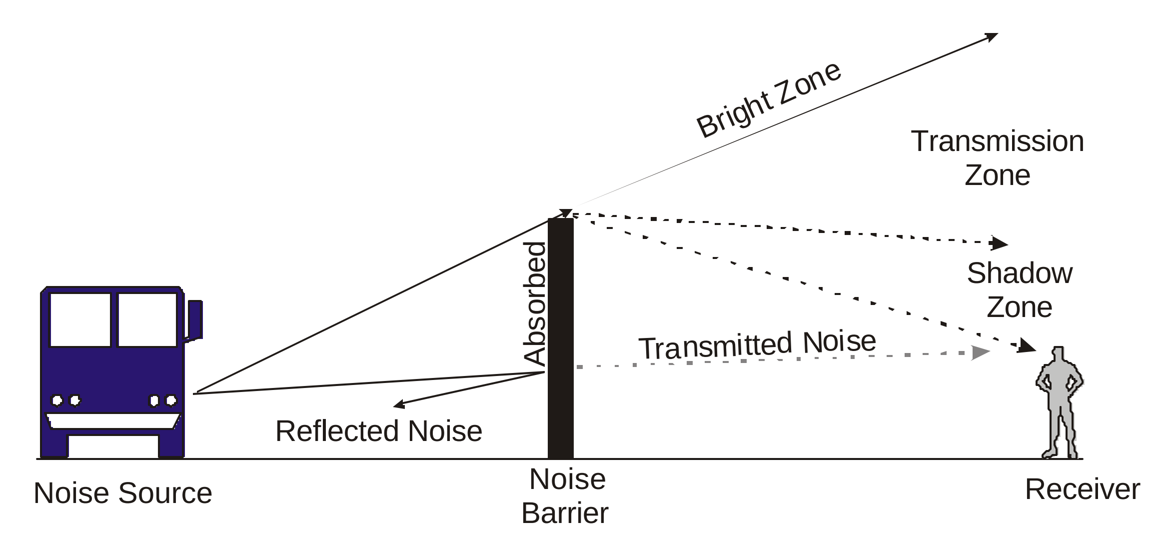
9.3.1 Noise Barrier Basics

Several aspects of noise barrier design can help to assure that sufficient noise reduction characteristics are achieved and that WSDOT criteria are met. Noise barriers or berms should do more than break the line-of-sight between the noise source and the receiver.

Noise barriers should be long enough to prevent significant diffraction of noise around the ends of the walls. Openings in walls, such as for driveways and pedestrian access, can significantly reduce barrier effectiveness.

Other items that can impact the overall effectiveness of noise barriers include the horizontal placement, topography between the receiver and the project corridor, and the elevation relationship between the receiver, noise barrier, and roadway. In general, noise barriers are most effective if placed close to the noise source or close to the receiver location. In addition, if the sensitive receivers are located above the roadway grade, the overall effectiveness of the noise barrier can be significantly reduced unless it is placed at the same elevation as the receptor. Finally, noise barriers are normally most effective for receivers located close to the project corridor. For distances greater than 300 feet, the relative effectiveness of noise barriers would become negligible.

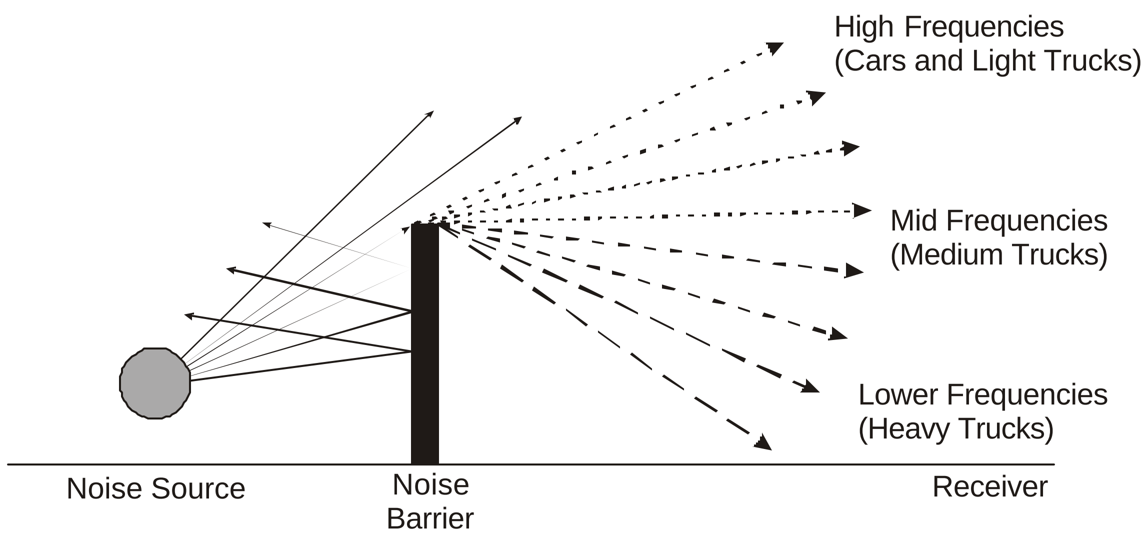
As shown in Figure 4, noise barriers reduce transportation noise by absorbing it, or by reflecting it back across the highway or upward. Reflected noise is the noise that moves back toward the traffic after hitting the noise barrier. Some noise would be diffracted over the barrier, while a small amount of noise would be transmitted through or absorbed by the barrier. The bright zone is the area above the barrier with a line-of-sight to the noise source. The other two zones are the transmission zone and the shadow zone. The transmission zone contains some noise that is directly transmitted by the noise source, along with some noise that is diffracted over the wall. The shadow zone is primarily all diffracted noise.



Source: Adapted from *FHWA Highway Noise Barrier Design Handbook* (FHWA, 2001)

Figure 4. Barrier Absorption, Transmission, Reflection, and Diffraction

Diffraction, or the bending of sound waves around an obstacle, can occur both at the top of the barrier and around the ends. Diffraction is much like other wave phenomena, such as light and water waves. Because of the nature of sound waves, diffraction does not bend each frequency uniformly. Higher frequencies (shorter wavelengths) are diffracted to a lesser degree, while lower frequencies (longer wavelengths) are diffracted deeper into the "shadow" zone behind the barrier. As a result, a barrier is generally more effective in attenuating higher frequencies than lower frequencies, as shown on Figure 5. The figure also displays that noise barriers are generally less effective at reducing the lower frequencies associated with heavy trucks, and more effective at reducing noise from passenger vehicles. This figure also helps to explain why higher noise barriers are necessary for highways with a high level of heavy truck traffic.



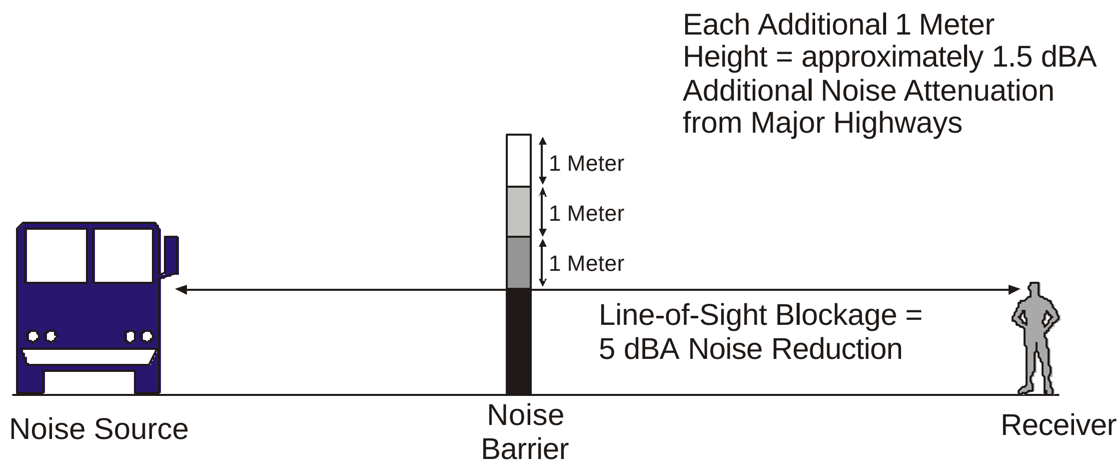
Source: Adapted from *FHWA Highway Noise Barrier Design Handbook* (FHWA, 2001)

Figure 5. Noise Barrier Diffraction Characteristics

9.3.2 Effective Noise Barrier Feasibility Design Considerations

Normally, noise barriers are only recommended for construction by WSDOT if the wall can be shown to be an effective form of noise mitigation. An effective noise barrier should achieve a minimum average noise reduction of 5 dBA for front-line receivers, with at least one receiver obtaining a 7 dBA noise-level reduction (see page 11 of the *Traffic Noise Analysis and Abatement Policy and Procedures* [WSDOT, 1997]). Typically, noise barriers can achieve a 10 dBA noise reduction for receivers located directly behind the barrier, with second-line receivers receiving a noise reduction of 3 to 6 dBA, depending on the distance from the barrier. According to FHWA, a properly designed noise barrier should provide noise reductions approaching 10 dBA for front-line receivers (see Section 3.5.1 of the *FHWA Highway Noise Barrier Design Handbook* [FHWA, 2001]). Proper design includes correct placement between the receiver and the noise source, and sufficient height to achieve the desired reduction.

Generally, for major highways, once the line-of-sight is broken, an additional 1.5 dBA reduction can be achieved for each 1-meter increase in height (Figure 6).



Source: Adapted from *FHWA Highway Noise Barrier Design Handbook* (FHWA, 2001)

Figure 6. Noise Barrier Height Design Considerations

Two factors to consider when determining barrier height are the design feasibility and cost. There is a point at which the additional noise reduction does not justify the additional cost. Noise barriers over 16 feet high are often costly to design and build, and only provide a minimal additional noise reduction. Achieving noise reductions over 12 dBA from noise barriers is very difficult, and often costs far too much to make the barrier feasible. A general relationship between noise reduction and design feasibility is given in Table 7.

Table 7. Relationship Between Barrier Noise Reduction and Feasibility[a]

Noise Reduction	Feasibility	Relative Reduction in Loudness
5 dBA	Simple	Readily Perceptible
10 dBA	Attainable	Half as Loud
15 dBA	Very Difficult	One-third as Loud
20 dBA	Nearly Impossible	One-fourth as Loud

[a] Adapted from *FHWA Highway Noise Barrier Design Handbook* (FHWA, 2001)

Other factors, such as construction considerations and safety and potential barrier reflections, are also considered when determining if a noise barrier is feasible. If these criteria are met and the wall meets the WSDOT cost-effectiveness criteria (see Section 9.3.3), the wall may be recommended for construction as part of the project

9.3.3 WSDOT Noise Barrier Feasibility and Cost Criteria

Every reasonable effort should be made to attain a 10 dBA (or greater) insertion loss at the first row of receivers. For a noise barrier to be considered a feasible form of mitigation, most of the first row of receivers must achieve a 5 dBA insertion loss and at least one receiver must have a 7 dBA reduction in noise levels. For most projects, noise barrier construction is feasible if a 7 dBA noise reduction can be achieved.

Safety factors that should be considered in the feasibility assessment of the noise abatement include maintaining a clear recovery zone, redirection of errant vehicles, adequate sight distance, and fire/emergency vehicle access. The consideration of the abatement should also include potential environmental impacts to wetlands, historic properties, parklands, property access, utility placement, etc.

WSDOT has established cost-effectiveness criteria for the construction of noise barriers. The criteria were established to assure that if a noise barrier is recommended, the cost of the noise barrier is consistent with the level of reduction and does not cost an excessive amount.

Once the construction of a noise barrier has been determined to be feasible, WSDOT will determine whether its construction is reasonable by thoroughly considering a wide range of criteria, as discussed below. Noise barriers will only be constructed by WSDOT if they have been determined to be reasonable. The decision whether or not to recommend that a noise barrier be implemented will normally be the responsibility of the Regional Traffic Noise Abatement Manager with concurrence from design personnel. Reasonableness will be determined based on the factors discussed below.

1. Noise levels in the design year approach or exceed the noise abatement criteria in Table 4, Section 5.4, or qualify as a substantial exceedance.

2. Most of the first row of receivers obtain a minimum 5 dBA insertion loss, and at least one receiver has a minimum 7 dBA reduction.

3. The noise mitigation cost per residence (or residential equivalent) is at or less than indicated in Table 8 below. This is determined by counting all residences (including owner-occupied, rental units, mobile homes) that have benefited by at least 3 dBA because of the noise barrier in any subdivision and/or given development, and by dividing that number into the total cost of the noise abatement measure. Each unit in a multi-family building will be counted as a separate residence. Table 8 below shows that as the predicted future noise-level increases, it is reasonable to implement more costly measures, if necessary, to mitigate traffic noise.

Table 8. Cost Allowance for Impacts Caused by Total Traffic-Noise Levels

Design Year Traffic Noise Decibel Level	Allowed Cost Per Household[a]	Equivalent Wall Surface Area Per Household
66 dBA	$15,500	65.0 m^2 (700 ft^2)
67 dBA	$17,000	71.5 m^2 (770 ft^2)
68 dBA	$18,500	77.7 m^2 (837 ft^2)
69 dBA	$20,000	84.0 m^2 (905 ft^2)
70 dBA	$21,500	96.7 m^2 (973 ft^2)
71 dBA	$23,000	97.5 m^2 (1,041 ft^2)
72 dBA	$24,500	103.0 m^2 (1,109 ft^2)
73 dBA	$26,000	109.2 m^2 (1,176 ft^2)
74 dBA	$27,500	115.5 m^2 (1,244 ft^2)

[a] Based on $22.10 per square foot construction cost (per square foot cost subject to modification by WSDOT).

Property use should be included when considering the reasonableness of abatement. For example, churches and parks may be in use only during specific hours or days of the week. These same facilities generally have a greater number of receivers than if simply counted as a residence. In these cases, residential equivalents, as defined in the *Traffic Noise Analysis and Abatement Policy and Procedures Manual* (WSDOT, 1997), must be used.

Noise barriers should be considered where land use is changing rapidly and where there are local zoning laws or ordinances to control the development of noise-sensitive land uses adjacent to transportation corridors. An exception would be considered for areas with well-established sensitive uses, such as residential subdivisions, where the local government has agreed in writing to implement measures to prohibit the development of non-sensitive land uses within and adjacent to those sensitive land uses.

The relationship of the location of a noise barrier to the receptors to be protected should be considered when making a reasonableness determination. For example, very tall barriers located very close to the receptors can have a significant negative visual impact.

The next three sections provide typical cross-sectional views of noise barriers for receivers that are at-grade, below-grade, and above-grade. In addition, information about placement of barriers on structures and about the treatment and aesthetics of noise barrier surfaces is also included.

9.3.4 Noise Barriers with Receivers At-Grade

For receivers located at a similar grade as the project corridor, noise barriers can be a very effective mitigation method. For projects like the Trans-Lake Washington Project, noise barriers would normally be placed close to the roadway within the project corridor right-of-way. The height of noise barriers varies with vehicle mix and location of receivers (Figure 7). For receivers located at-grade with the Trans-Lake Washington Project, the expected wall height would be 12 to 14 feet high. Walls of this height are normal for major highways with moderate-to-high levels of heavy truck traffic and receivers located at approximately the same grade as the roadway.

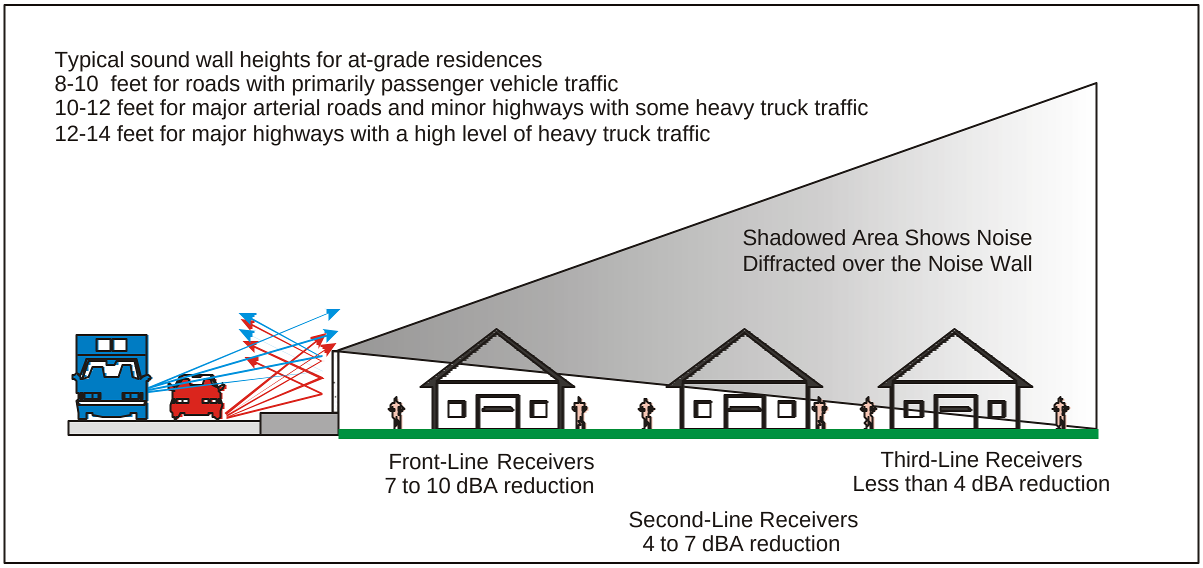


Figure 7. Typical Noise Barrier Effectiveness with Receiver At-Grade

9.3.5 Noise Barriers with Receivers Below-Grade

For locations where the receivers are located below-grade, the overall effectiveness of a noise barrier is increased. Since the receivers are located below-grade, less of the noise diffracted over the top of the noise barrier reaches the receivers. In most cases, the wall height can be lower and still provide the same level of noise reduction, as shown for receivers located at the same grade as the roadway. Typical noise barrier heights for below-grade receivers are 2 to 4 feet less than for at-grade receivers. The actual height of the wall will again depend on wall placement, distance from the receiver, and vehicle mix. Figure 8 provides a typical schematic of wall heights and relative effectiveness for receivers located below the road grade.

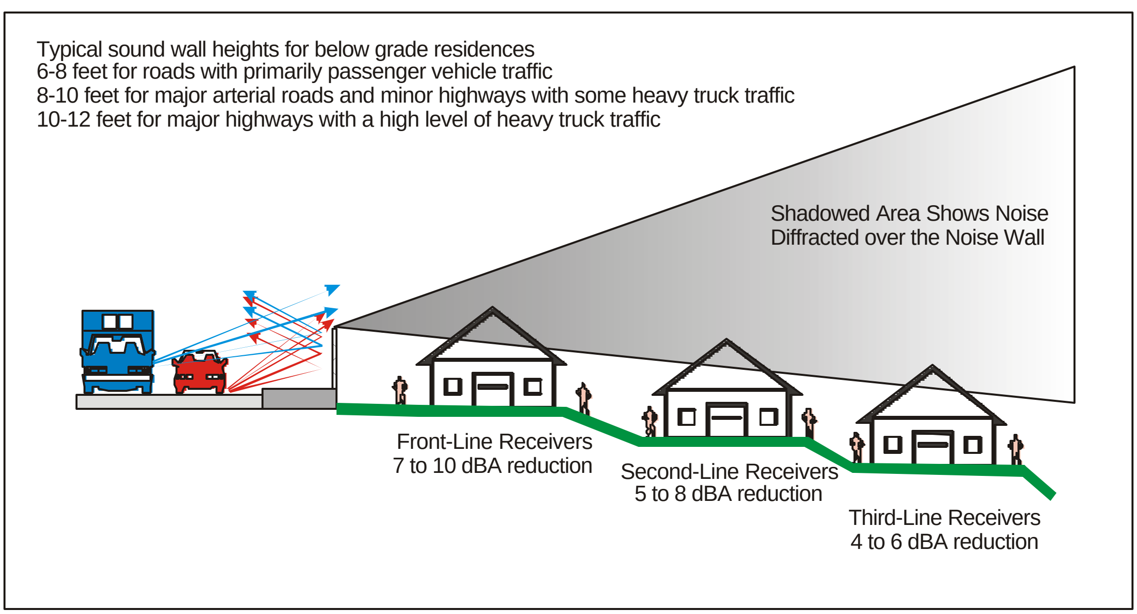


Figure 8. Typical Noise Barrier Effectiveness with Receiver Below-Grade

9.3.6 Noise Barriers with Receivers Above-Grade

For locations where receivers are elevated above the roadway, noise barriers are normally less effective at reducing transportation noise. The mitigation is less effective because the receivers are closer to noise that is diffracted over the top of the noise barrier. Increasing the height of the noise barrier can, in some circumstances, result in noise reductions of the same magnitude that would be achieved for at-grade receivers. The overall effectiveness depends on the level of elevation over the roadway, vehicle mixture, wall placement, and other geometric considerations. Figure 9 provides a typical schematic of wall heights and relative effectiveness for receivers located above the road grade.

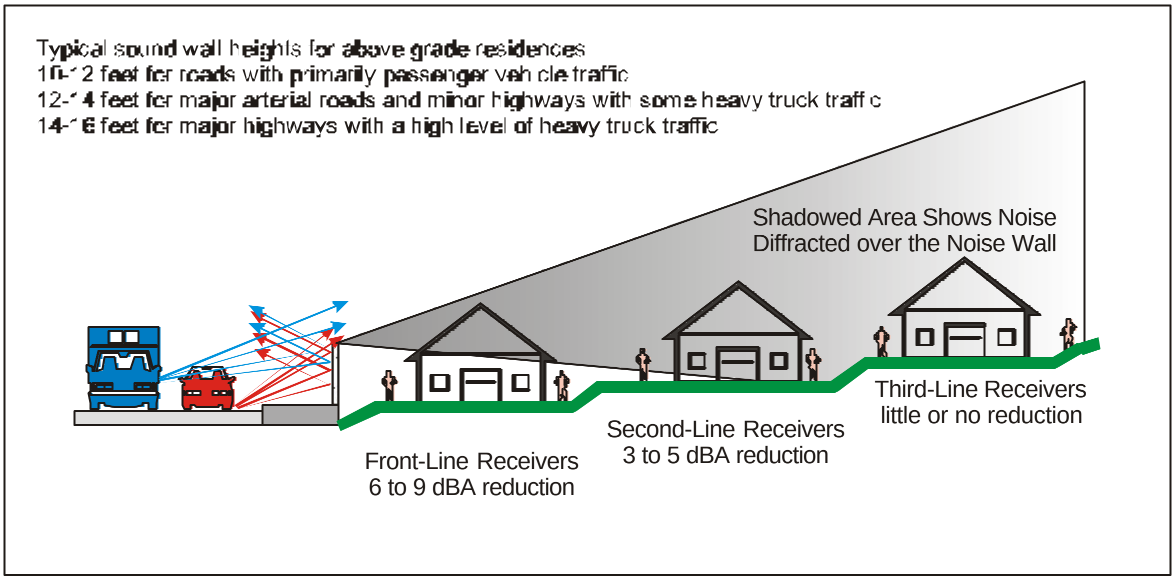


Figure 9. Typical Noise Barrier Effectiveness with Receiver Above-Grade

9.3.7 Noise Barriers on Structures

Typically, noise barriers on structures are considered only in extreme circumstances. This is mainly due to construction considerations and the additional weight required by the walls. FHWA recently released the *FHWA Highway Noise Barrier Design Handbook* (FHWA, 2001), which provides information on noise barrier design considerations when placing walls on structures. General design and construction-related information from the handbook is presented here, and is primarily intended for use by the project design team.

A number of techniques have been successfully employed to attach noise barriers to bridges. While somewhat different procedures and operations exist for attaching noise barriers to existing bridges compared to attaching noise barriers to new bridges, the resultant attachment types are similar enough to be discussed under the following general categories: (1) post and panel noise barriers on structures and (2) postless noise panels on structures.

9.3.7.1 Post and Panel Noise Barriers on Structures

Noise barriers may be placed on top of, inserted into, or mounted onto parapets.

- **On Top of Parapet.** Such attachments usually include high-strength bolts anchored to or embedded into the top of the parapet. In new construction, such bolts are often set in the parapet formwork prior to the concrete pour. In existing parapets, bolts may be anchored by mechanical fastening or chemical bonding (epoxy grout) methods. Depending on the type of noise barrier material, the high-strength anchored bolts and nuts are used to secure either a continuous horizontal beam (or angle) or vertical posts to the parapet.

  Noise barrier panels or other components are then secured to the beam or posts to create the in-place barrier. Obtaining a smooth or desired top-of-barrier profile with such a system may require each panel to be custom-made, if the top of the parapet profile is not smooth and/or consistent. Any bottom of barrier jaggedness or gapping can be concealed by flashing.

- **Inserted into Parapet**. This method is only considered feasible for new bridges. Although not as common as attachment techniques, posts have been inserted into the parapet itself (either prior to casting of the parapet, or after parapet casting) via insertion into precast holes within the parapet wall itself.

- **On Outside Face of Parapet**. Although suitable for existing and new bridges, it is particularly suitable for retrofitting of existing bridges. A common practice is to mount noise barriers onto the outside face of the parapet.

9.3.7.2 Postless Noise Panels on Structures

Such systems use either concealed posts or no posts with the panels typically mounted in the following manners:

- **On Top of Parapet**. For concealed post systems, the post to parapet connections are similar to those discussed above for the post and panel systems. For postless systems, the panels (typically constructed of relatively lightweight materials) are attached via bolts to two parallel angle iron pieces mounted onto the parapet.

- **On Outside Face of Parapet.** Such systems are mounted in manners similar to those for the post and panel systems listed above, except the panels themselves are bolted to or through the parapet. With this type of system, additional detailed care should be taken in the design of the horizontal joints between panels to assure a leak-free noise condition, and to maintain the consistent alignment of the adjacent panels.

9.3.7.3 Masonry Block Noise Barriers

These barriers are "laid up" in a manner similar to ground-mounted masonry block barriers, except that they are anchored to the protective concrete bridge parapet wall, which usually has the same shape as the standard concrete traffic barrier walls (Jersey barriers). The barriers are anchored with reinforcing bars that extend out of the top of the parapet wall. The noise barrier wall can be further strengthened by inserting reinforcing bars and concrete within the voids of the masonry blocks.

9.3.7.4 Cast-in-Place Integral with Parapet Wall

On occasions, it may be necessary and appropriate to construct noise barriers integral with the bridge parapet wall. This type of structure-mounted noise barrier wall is more suitable where short barriers can provide the desired noise attenuation, or in situations where it may be the only possible option due to restrictions in erecting any other type of barrier system.

Examples of typical bridge-mounted noise barriers are given on Figures 10 and 11. Additional research on bridge and structure-mounted noise barriers will be explored and may be used on the Trans-Lake Washington Project if these barriers meet the WSDOT criteria.

Figure 10. Example 1—Typical Structure-Mounted Noise Barrier

Figure 11. Example 2—Typical Structure-Mounted Noise Barrier

9.3.8 Noise Barrier Materials and Surface Treatments

FHWA and other agencies are currently considering several types of materials and surface treatments for noise barriers. Many of the walls using these materials and surface treatments and their effectiveness are described in detail in the new *Highway Noise Barrier Design Handbook* (FHWA, 2001). Wall materials and surface treatments to be reviewed for use on the Trans-Lake Washington Project include concrete, metal, wood, plastic, composite, and transparent materials. Final selection of surface materials should be consistent with other barriers in the project corridor and would be coordinated with the Washington State Architect.

9.3.8.1 Concrete

Almost half of the noise walls constructed in North America are made of concrete. For cast-in-place operations, concrete is normally delivered onsite and premixed by concrete truck; for small quantities, it can be mixed onsite. For precast products, manufacturers usually have their own batch plants capable of providing sufficient quantities to match production. Coloring or tinting can be added to concrete barriers by incorporating pigments into the concrete mix before pouring, or afterwards by applying a stain onto the surface of the cured products.

Precast panels can be erected quickly if crane and truck access is readily available. Traffic holdups can be minimized with offsite panel fabrication. Landscape damage can be avoided by using properly sized cranes that cover the landscaping when setting the panels. In some circumstances, however, the presence of both a crane and a haul truck, which are necessary during panel erection, can become a traffic problem necessitating a lane closure.

9.3.8.2 Brick and Masonry Block

Brick and masonry block walls can be either hand-laid or preassembled by machine. Hand-laid walls more easily conform to the variety of ground contours encountered in the roadway environment and in their layout than do the preassembled panels with their fixed panel sizes and heavy equipment requirements. Preassembled panels can be erected faster, if the necessary cranes and transport vehicles are able to maneuver over the site easily. In addition, brick and masonry block walls can be constructed satisfactorily with no special leveling courses on grades of up to 6 percent. In some cases, brick is used as a facing or veneer on masonry block or cast-in-place walls.

9.3.8.3 Metal

Three types of metals are most commonly used for noise barrier construction: steel, aluminum, and stainless steel. Metal panels have a weight advantage that makes them particularly useful for vertical extensions of existing sound walls, for mounting on existing retaining walls that have limited residual strength, or on bridge structures because of their light weight. Metal panels can be used anywhere; however, bridges and retaining walls are ideal locations for these lightweight type of panels.

9.3.8.4 Wood

A number of different wood species have potential as a noise barrier product. Given the requirements for the Trans-Lake Washington Project, however, wood is not considered a viable material for noise barriers and will probably not be used on this project. This is due primarily to the maintenance and safety issues associated with this type of barrier.

9.3.8.5 Plastic

There are several types of plastic materials available for use as a barrier material, including polyethylene, polyvinyl chloride (PVC), and fiberglass. In general, plastic barriers are lightweight and generally suitable for structure mounting. Additional research will be performed to determine if plastic barriers can be used on the Trans-Lake Washington Project. Initial review of this type of barrier indicates that, if necessary, it would be most likely used on structures.

9.3.8.6 Composite

Composite noise barrier materials, in general terms, can be defined as any product composed of two or more primary materials, such as plywood with a fiberglass skin or wood mixed with concrete and then layered onto concrete. There are several special considerations, including safety, durability, and performance, that would be evaluated prior to using any composite material on the Trans-Lake Washington Project.

9.3.8.7 Transparent Noise Walls

The typical transparent noise barrier may use panel material made of either glass or a clear plastic product such as Plexiglas®, Butacite®, Surlyn®, Lexan®, or acrylic. Glass panels are commonly made of single tempered or laminated tempered glass sheets. Both plastics and glass can be tinted and can also be etched or given a frosty appearance. It should be noted that due to maintenance concerns, WSDOT would not typically consider these types of noise barriers; however, there would most likely be no objection to second parties constructing and maintaining these types of noise barriers outside of the WSDOT right-of-way.

Transparent noise barriers are normally only built for one or more of the following reasons:

- To prevent hindering the scenic view for the driving public
- To prevent hindering the scenic view for the residents adjacent to the roadway
- To prevent hindering the view of retail establishments for the driving public

Since transparent noise barriers can cost as much as 20 more than common concrete or steel panels, the decision to use transparent noise barriers should not be made lightly.The only other possible reasons for their use would be to improve safety because opaque noise barrier walls may adversely affect stopping sight distance, visibility in merge areas, lighting, and shading.

Transparent noise barriers come with their own unique set of engineering, safety, and environmental considerations that are significantly different than most other types of material normally used for noise barrier panels.

- Plastic panels are particularly susceptible to vandalism, not only from the typical paint can, but also from knives, lighters, or matches.
- These types of panels are more susceptible to damage from flying debris than most other types of barrier materials. They are also very susceptible to the abrasive damage caused by the sand blasting action from stirred-up road dirt.
- To maintain their transparency, these types of panels need to be washed on a regular basis. This is of particular concern if access to the wall is limited. Access for panel cleaning is normally not a problem on the traffic side, which is usually the dirtier side of the wall. However, the opposite side may not be as accessible and, in some cases, cleaning may not be feasible at all. This limitation should be considered when selecting barrier material. Cleanliness is particularly critical if the transparent noise barrier is constructed for safety reasons such as to improve visibility for stopping sight distance or merging.
- Damaged panels cannot be repaired by patching. The only option is to replace the damaged sections.
- Given the cost, maintenance, and other issues associated with transparent noise barriers, it is unlikely that they would be selected as a form of noise mitigation for the Trans-Lake Washington Project.

9.3.8.8 Surface Textures and Coatings

A vast number of surface textures and coatings are available to the noise barrier designer (see Figure 12). In many cases, such treatments can be applied to several elements of the barrier systems (e.g., posts, panels, caps, etc.). Different barrier surface treatments can be obtained by having different combinations of treatments on these separate barrier elements. Surface textures and coatings can be applied for several reasons, including aesthetics, material protection, sound diffusion, and protection from vandalism, such as graffiti coatings. Surface textures and coatings may be used to supplement the mitigation along the Trans-Lake Washington Project corridor as necessary.

Figure 12. Noise Barrier Surface Treatment Samples

9.4 SOUND INSULATION PROGRAMS

Sound insulation programs, commonly called Residential Sound Insulation Programs (RSIPs), are normally performed only for high capacity transit projects such as light rail and commuter rail, when nighttime operations result in noise impacts that cannot be mitigated through conventional methods. Occasionally, RSIPs will be used for highway projects; however, the practice is usually only performed for institutional type land uses such as schools. For the Trans-Lake Washington Project, multi-modal transportation systems might be included in the SR 520 corridor area; therefore, an RSIP may be used in select areas for noise-sensitive public facilities.

An RSIP is accomplished by measuring the exterior-to-interior noise reduction characteristics of a particular structure to determine if the structure meets the appropriate interior noise standard. For high capacity transit projects, the preferred standard is the Housing and Urban Development (HUD) standard of 45 dBA L_{dn} for living quarters. For traffic noise, the FHWA interior peak-hour criterion of 52 dBA L_{eq} is normally used. If the interior noise levels are in compliance, then no further mitigation is required. If the interior noise levels exceed the criteria, then modifications to the structure are performed that reduce the interior noise levels to within the criteria.

Modifications include updating or replacing windows, doors, and wall and ceiling insulation. In addition to these structural modifications, some form of air-exchange system, such as HVAC, is also added to the structure to allow fresh air circulation without opening the windows. Because of the HUD requirement for fresh air circulation, this practice is normally required unless some form of air exchange already exists at the structure.

There are several issues to be considered with the RSIP form of mitigation, including the condition of the structure, area land use, and project-related noise levels. In addition, RSIP does not reduce the noise-level directed toward the structure, and therefore does not provide any measurable noise reduction at the exterior. Furthermore, an RSIP can be very expensive because acoustical testing is necessary prior to performing any of the referenced structural updates. Finally, the condition of an impacted structure often cannot be determined until modifications are begun, and occasionally structures are simply not worth the cost to perform the necessary improvements. For these reasons, RSIPs are only considered if all other methods of noise mitigation have been exhausted and significant impacts still exist.

10. CONCLUSIONS AND RECOMMENDATIONS

There are several methods of reducing noise from transportation-related projects. The Trans-Lake Washington Project poses some unique and difficult situations that may require creativity with respect to noise abatement and mitigation measures. Continued research will be performed and used wherever and whenever possible during the Trans-Lake Washington Project. In addition, meetings with the Trans-Lake design team and the local community will be held. Concerns and comments identified during these meetings will be taken into consideration.

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Appendix A: Measurement Descriptors

General Measurement Descriptors and Equations

- **L_{Pa} (A-weighted sound pressure level).** The sound pressure in dB is 20 times the log of the ratio of the measured A-weighted pressure, p, to the static pressure, p_o, where p_o is 20 µPa.

$$L_{PA} = 20\mathrm{Log}_{10}\left(\frac{p_A}{p_0}\right) dBA \;\; re\ 20uPa$$

- **L_{eq} (equivalent continuous sound level).** The constant sound level in dBA that, lasting for a time "T," would have produced the same energy in the same time period "T" as an actual A-weighted noise event.

$$L_{eq} = 10\mathrm{Log}_{10}\frac{1}{T}\int_0^T\left(\frac{p(t)}{p_o}\right)^2 dt$$

- **L_{min} (minimum A-weighted RMS sound level).** The lowest sound level, in dBA, measured during the preset measurement period.

- **L_{max} (maximum A-weighted RMS sound level).** The greatest RMS (root-mean square) sound level, in dBA, measured during the preset measurement period.

- **MaxPeak (maximum A-weighted sound level).** The greatest sound level, in dBA, measured during the preset measurement period.

Community Noise-level Descriptors

The following sound level descriptors are commonly used in community noise measurements:

- **L_{dn} (day-night average sound level).** A 24-hour equivalent continuous level in dBA where 10 dB is added to nighttime noise levels from the hours of 10:00 p.m. to 7:00 a.m.

- **CNEL (community noise equivalent level)**. A 24-hour equivalent continuous level in dBA where 5 dBA is added to evening noise levels from 7:00 p.m. to 10:00 p.m. and 10 dBA is added to nighttime noise levels from 10:00 p.m. to 7:00 a.m.

- **SEL (sound exposure level)**. That constant level in dBA that, lasting for 1 second, has the same amount of acoustic energy as a given A-weighted noise event lasting for a period of time T. This measurement is most commonly used for airport noise.

Commonly Used L_{xx} Noise-level Descriptors

- L_{01} The sound level is exceeded 1 percent of the time. This is a measure of the loudest sound levels during the measurement period. Example: During a 1-hour measurement, an L_{01} of 95 dBA means the sound level was at or above 95 dBA for 36 seconds.

- L_{10} The sound level is exceeded 10 percent of the time. This is a measure of the louder sound levels during the measurement period. Example: During a 1-hour measurement, an L10 of 85 dBA means the sound level was at or above 85 dBA for 6 minutes.

- L_{50} The sound level is exceeded 50 percent of the time. This level corresponds to the median sound level. Example: During a 1-hour measurement, an L_{50} of 67 dBA means the sound level was at or above 67 dBA for 30 minutes.

- L_{90} The sound level is exceeded 90 percent of the time. This is a measure of the nominal background level. Example: During a 1-hour measurement, an L_{90} of 50 dBA means the sound level was at or above 50 dBA for 54 minutes.

- L_{99} The sound level is exceeded 99 percent of the time. This is the quietest or minimum level during the measurement period. Example: During a 1-hour measurement, an L_{99} of 42 dBA means the sound level was at or above 42 dBA for 59 minutes and 24 seconds.

Appendix B: Washington State Construction-Specific Noise Regulations

This appendix contains a summary of the WAC construction specific noise regulations. It should be noted that additional research on local construction related noise ordinances and standards will be performed during the environmental phase, and may be more stringent than those presented here. Under those circumstances, construction noise may be required to meet the local ordinance or standard or obtain a noise variance.

A) **General Equipment:** For construction activities, the limits set in Table 2, Section 5.6, may be exceeded between the hours of 7:00 a.m. and 10:00 p.m. on weekdays, and 9:00 a.m. and 10:00 p.m. on weekends according to the following limits:

B)

Allowable Exceedance	Equipment Covered
Twenty-five (25) dBA	Equipment on construction sites, including but not limited to crawlers, tractors, dozers, rotary drill and augers, loaders, power shovels, cranes, derricks, graders, off-highway trucks, ditchers, trenchers, compactors, compressors, and pneumatic powered equipment
Twenty (20) dBA	Portable powered equipment used for temporary locations in support of construction activities, such as chain saws, log chippers, lawn and garden equipment and powered hand tools
Fifteen (15) dBA	Powered equipment used in temporary repair or periodic maintenance of the grounds such as lawn mowers and powered hand tools.

C) **Impact Equipment:** Including but not limited to pavement breakers, pile drivers, jackhammers, sandblasting tools, or other types of equipment or devices that create impulse noise or impact noise or are used as impact equipment, as measured at the property line or at 50 feet from the equipment, which ever is greater, may exceed the limits given above in any one-hour period between the hours of 8:00 a.m. and 5:00 p.m. on weekdays and 9:00 a.m. and 5:00 p.m. on weekends, but in no event to exceed the following limits:

Maximum Hourly L_{eq}	Allowable Time for Sound Level Exceedance
90 dBA	Continuously
93 dBA	Thirty Minutes
96 dBA	Fifteen Minutes
99 dBA	Seven and One-half Minutes

D) **Haul Trucks:** Maximum permissible sound levels for haul trucks are limited to 86 dBA for speeds of 35 mph or less, and 90 dBA for speeds over 35 mph.

E) **Alarms:** Sounds created by back-up alarms are exempt if operated for less than 30 minutes per incident.